A Model-Independent Test on Variations in the Peak Luminosity of Type Ia Supernovae.

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Cosmology from Home
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Work Based on
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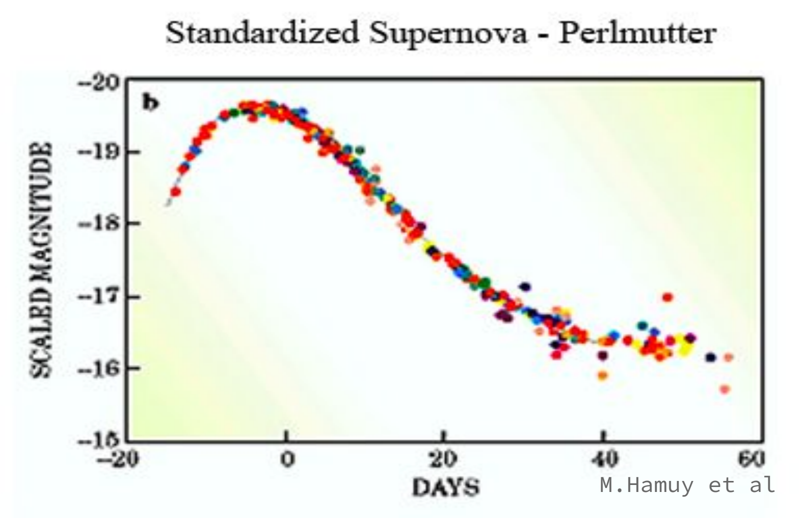
Motivation:

- **Type Ia SNa: Standard Candle:** direct evidence for the accelerating universe
  - ➡️ **Assumption:** Intrinsic Luminosity (or M_B) independent to redshift
  - ➡️ **Intrinsic Luminosity Depends:**
    - ✧ Host morphology
    - ✧ Host mass
    - ✧ Local star formation rate
- **AIM** ➡ Evolution of Luminosity with time or redshift!



M.Hamuy et al

Contents:

Basics of Cosmology:

- **Cosmological Principle:** Spatially Homogeneous and Isotropic at large scale.

- **The Friedmann–Lemaître–Robertson–Walker metric:**

$$ds^2 = -dt^2 + a^2(t)\left[\frac{dr^2}{1-kr^2} + r^2 d\theta^2 + r^2 \sin^2\theta d\phi^2\right]$$

where, $a(t) =$ Scale factor , $c = 1, k = -1, 0, +1$ for open, flat, close universe.

- **Einstein Equations:**

$$R_{\mu\nu} - \frac{1}{2} R g_{\mu\nu} + \Lambda g_{\mu\nu} = 8\pi G T_{\mu\nu}$$

$R_{\mu\nu} =$ Ricci tensor, $R =$ Ricci scalar, $g_{\mu\nu} =$ Metric tensor $\&\Lambda =$ Cosmological constant.

Cosmology Overview:

- **Energy Momentum Tensor:**

$$T^{\mu\nu} = (P + \rho)\, u^{\mu} u^{\nu} + P g^{\mu\nu}$$

u^{μ} is 4-velocity, P and ρ are pressure and energy density of perfect fluid.

- **Friedmann Equations:**

$$3\frac{\dot{a}^2 + k}{a^2} - \Lambda = 8\pi G\rho$$

$$2\frac{\ddot{a}}{a} + \frac{\dot{a}^2 + k}{a^2} - \Lambda = -8\pi GP$$

$$\frac{\ddot{a}}{a} = \underset{\substack{\Big\uparrow \\ \text{Slow down expansion}}}{-}\frac{4\pi G}{3}(\rho + 3P) \underset{\substack{\Big\uparrow \\ \text{Speed up expansion}}}{+} \frac{\Lambda}{3}$$

Basics of Cosmology:

- **Hubble Parameter:**

$$H(z) \equiv H_0 E(z) = H_0 \sqrt{\Omega_{m0}(1+z)^3 + \Omega_{k0}(1+z)^2 + \Omega_{\Lambda 0}}$$

$$H_0 = \frac{\dot{a}\left(t_0\right)}{a\left(t_0\right)} = \text{ Hubble Constant}$$

- **Cosmological Redshift:**

$$z \equiv \frac{\lambda_0 - \lambda_e}{\lambda_e} \qquad \frac{a\left(t_0\right)}{a\left(t_e\right)} \equiv z + 1$$

- **Cosmological Density Parameters:**

$$\Omega_{m0} = \frac{8\pi G \rho_m}{3H_0^2}; \quad \Omega_{k0} = \frac{-k}{H_0^2 a_0^2}; \quad \Omega_{\Lambda 0} = \frac{\Lambda}{3H_0^2}$$

$$\boxed{\Omega_{m0} + \Omega_{k0} + \Omega_{\Lambda 0} = 1}$$

Distances in Cosmology:

- Comoving Distance:

$$d_{co} = \frac{d_p(z)}{\left(\frac{a(t)}{a(t_0)}\right)} = (1+z)d_p(z)$$

- Angular Diameter Distance: Standard Ruler

$$d_A(z) = \frac{d_{co}}{1+z}$$

- Luminosity Distance: Standard Candle

$$d_L(z) = d_{co}(1+z)$$

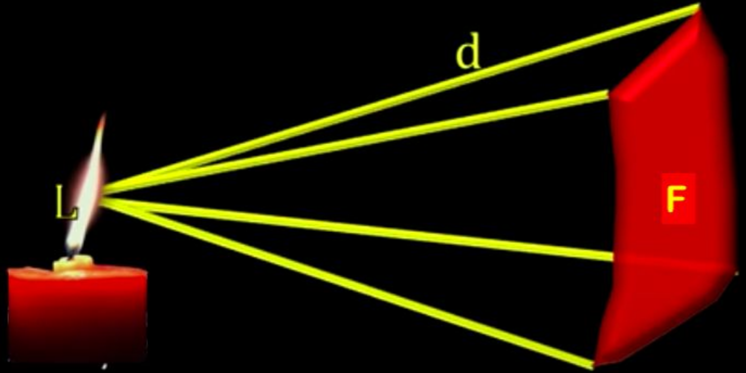
Distances in Cosmology:

$$d_A(z) = \frac{d_{co}}{(1+z)} = \frac{d_L(z)}{(1+z)^2} = \begin{cases} \dfrac{1}{(1+z)H_0\sqrt{\Omega_{k0}}} \sinh\left(\sqrt{\Omega_{k0}} \displaystyle\int_0^z \frac{dz'}{E(z')}\right) & \text{for } \Omega_{k0} > 0 \\ \dfrac{1}{(1+z)H_0} \displaystyle\int_0^z \frac{dz'}{E(z')} & \text{for } \Omega_{k0} = 0 \\ \dfrac{1}{(1+z)H_0\sqrt{-\Omega_{k0}}} \sin\left(\sqrt{-\Omega_{k0}} \displaystyle\int_0^z \frac{dz'}{E(z')}\right) & \text{for } \Omega_{k0} < 0 \end{cases}$$

Standard Candle: Type Ia Supernova

- **Flux:**

$$F = \frac{L}{4\pi d_L^2}$$



- **Luminosity Distance:**

$$d_L(z; M_B) = 10^{(m_B - M_B - 25)/5} \quad [Mpc]$$

- **CDDR:**

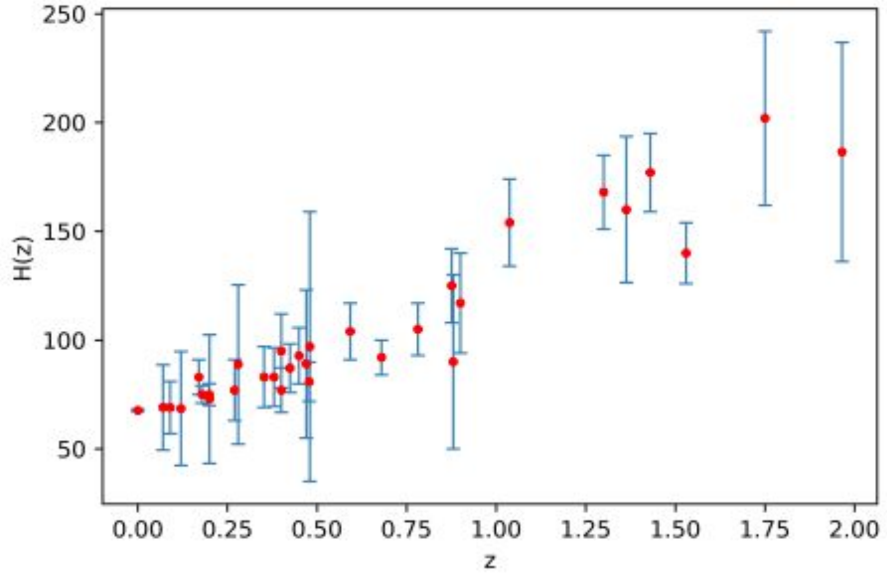
$$d_A = \frac{d_L}{(1+z)^2}$$

$$\boxed{m_B(z; \Omega_{k0}, M_B) = 5\log_{10}\left(d_A(z;\Omega_{k0})(1+z)^2\right) + M_B + 25}$$

Observable Datasets:

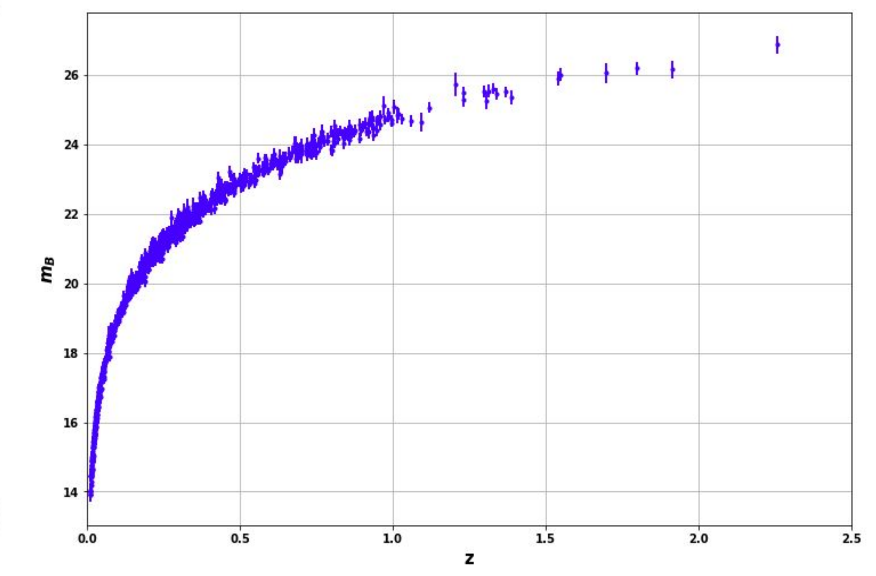
🔵 Hubble Parameter Dataset (CC):

31 data points of H(z) with redshifts in the range 0 < z < 2



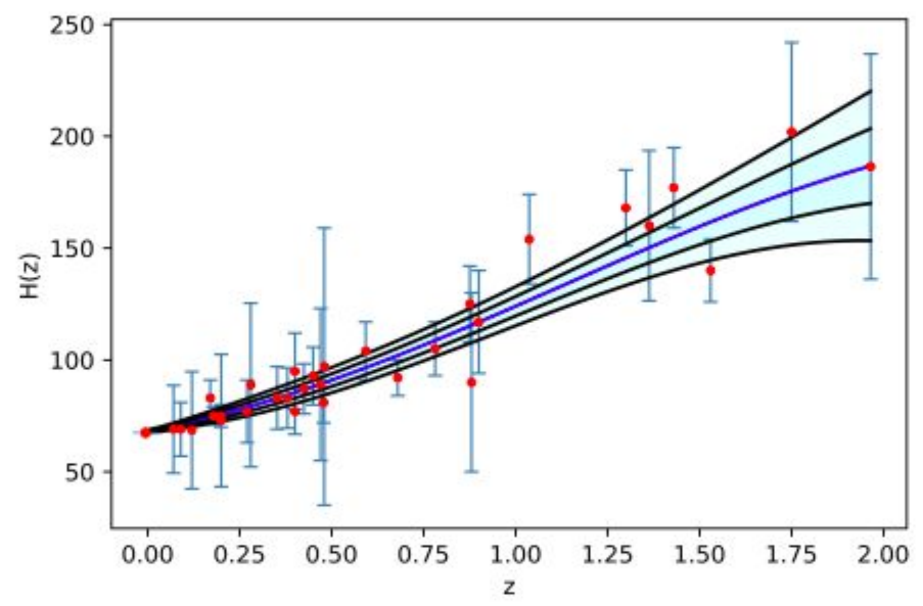
🔵 SNIa Dataset (Pantheon):

1048 data points of m(z) with redshifts in the range 0 < z < 2



Statistical Tools:

- **Dataset Reconstruction [GP]:**



- **Parameter Estimation [EMCEE]:**

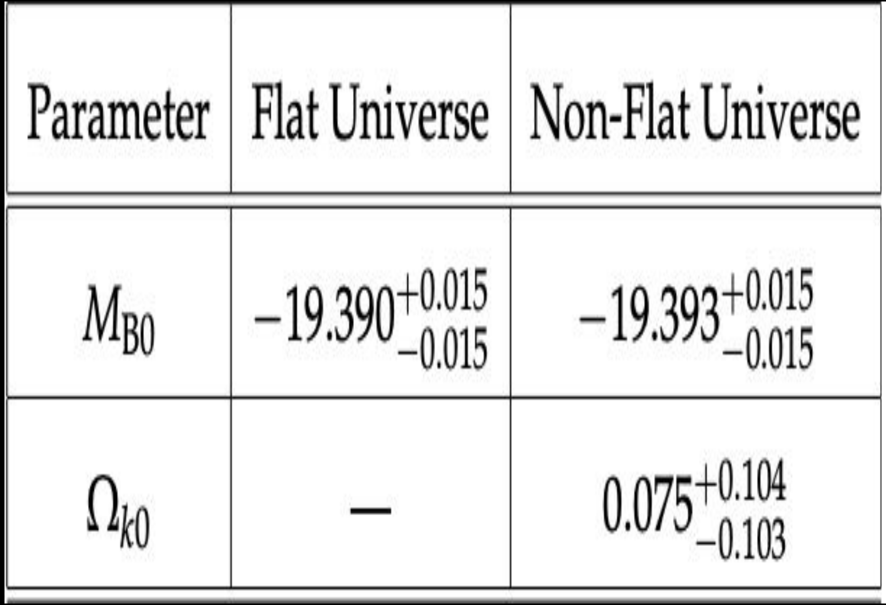
$$\chi^2 = \Delta m^T \cdot C^{-1} \cdot \Delta m$$

$$\Delta m = m_B^{\mathrm{obs}}(z_i) - m_B^{\mathrm{th}}(z_i; \eta, M_{\mathrm{B}}, \Omega_{k0})$$

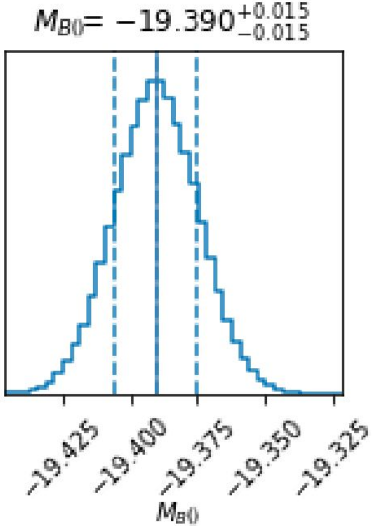
$$C = D_{\mathrm{stat}} + C_{\mathrm{sys}}$$

Results: arXiv:2107.04784

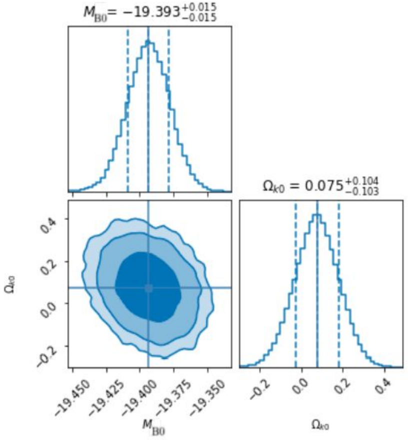
- **P1.** $M_B = M_{B0}$



Parameter	Flat Universe	Non-Flat Universe
M_{B0}	$-19.390^{+0.015}_{-0.015}$	$-19.393^{+0.015}_{-0.015}$
Ω_{k0}	—	$0.075^{+0.104}_{-0.103}$



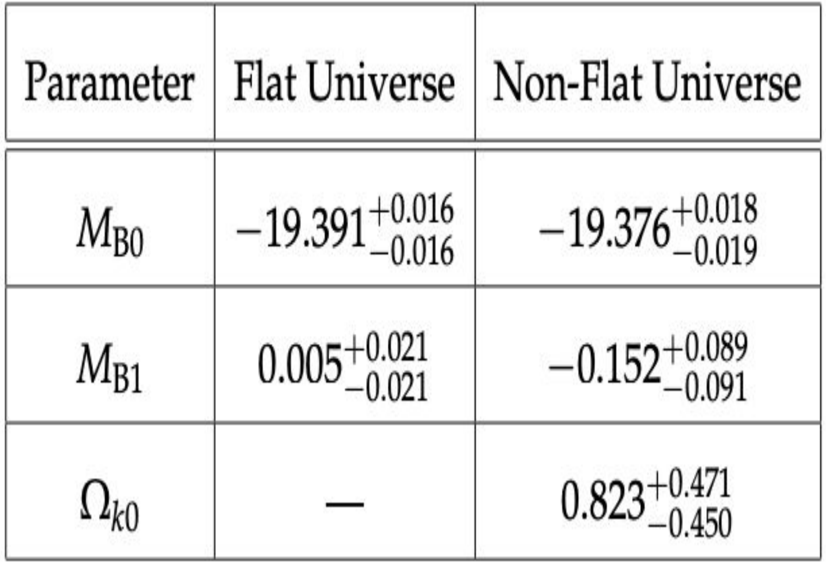
(a) Flat Universe



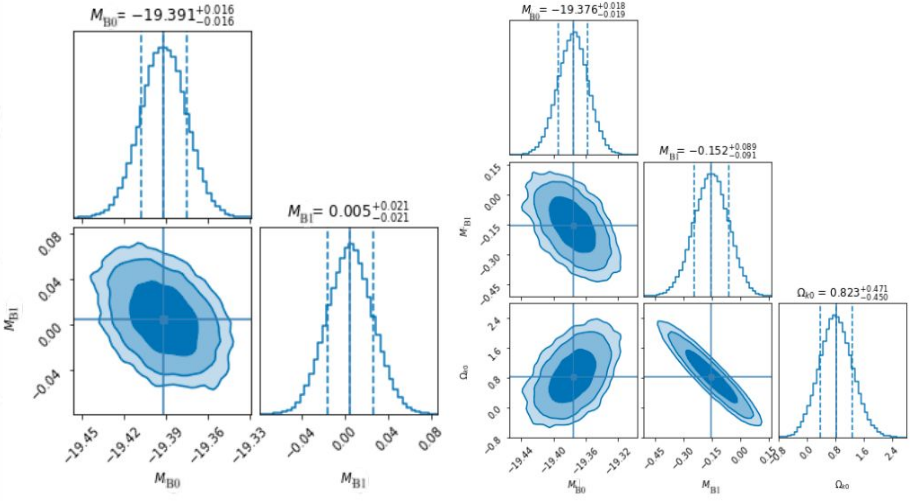
(b) Non-Flat Universe

Results: arXiv:2107.04784

- **P2.** $M_B = M_{B0} + M_{B1} z$



Parameter	Flat Universe	Non-Flat Universe
M_{B0}	$-19.391^{+0.016}_{-0.016}$	$-19.376^{+0.018}_{-0.019}$
M_{B1}	$0.005^{+0.021}_{-0.021}$	$-0.152^{+0.089}_{-0.091}$
Ω_{k0}	—	$0.823^{+0.471}_{-0.450}$

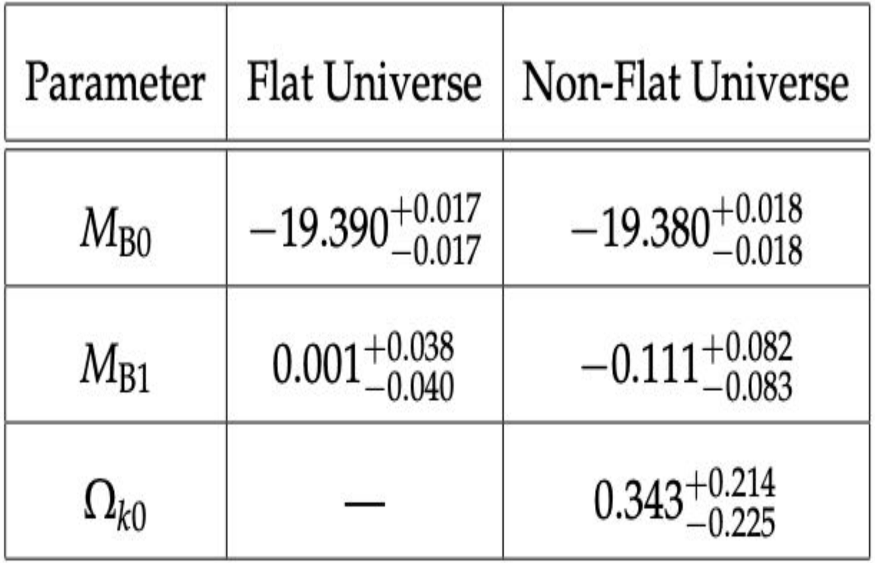


(a) Flat Universe

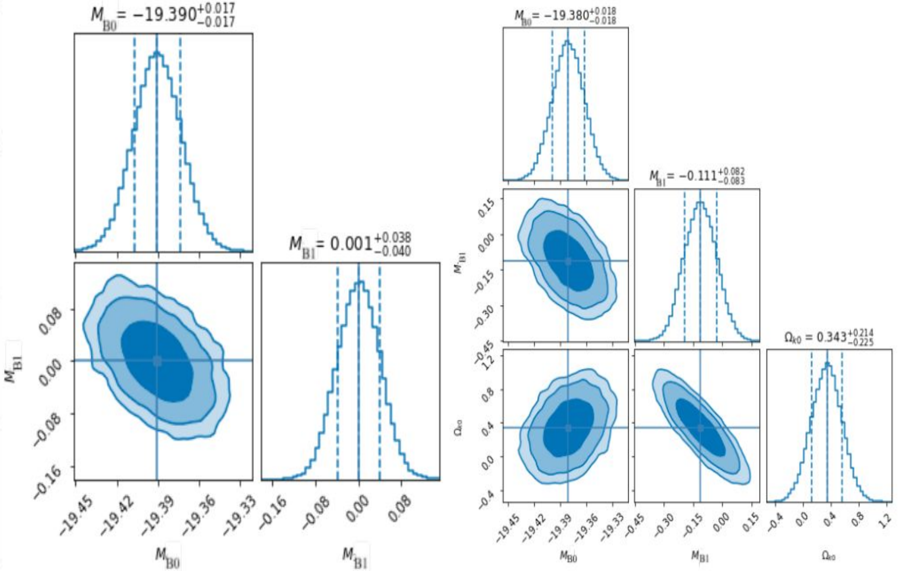
(b) Non-Flat Universe

Results: arXiv:2107.04784

- **P3.** $M_B = M_{B0} + M_{B1}\frac{z}{1+z}$

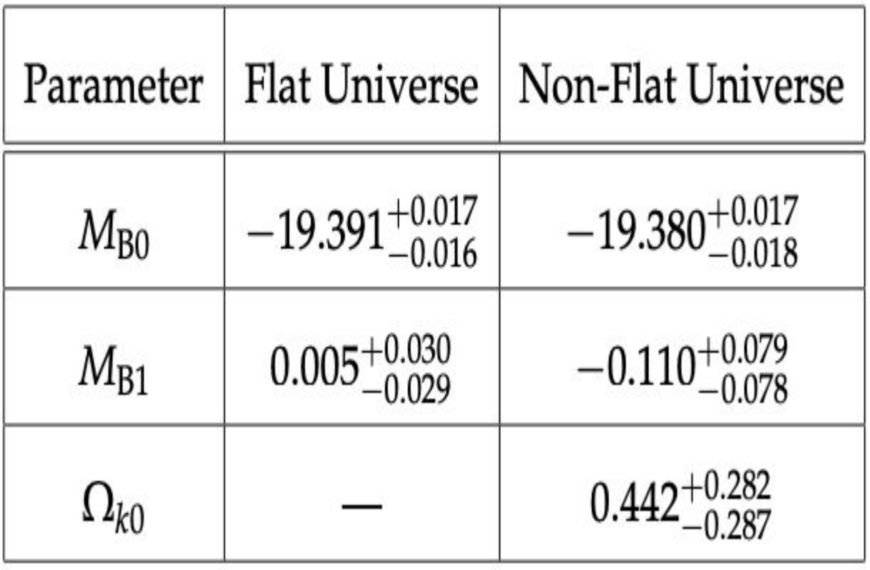


Parameter	Flat Universe	Non-Flat Universe
M_{B0}	$-19.390^{+0.017}_{-0.017}$	$-19.380^{+0.018}_{-0.018}$
M_{B1}	$0.001^{+0.038}_{-0.040}$	$-0.111^{+0.082}_{-0.083}$
Ω_{k0}	—	$0.343^{+0.214}_{-0.225}$

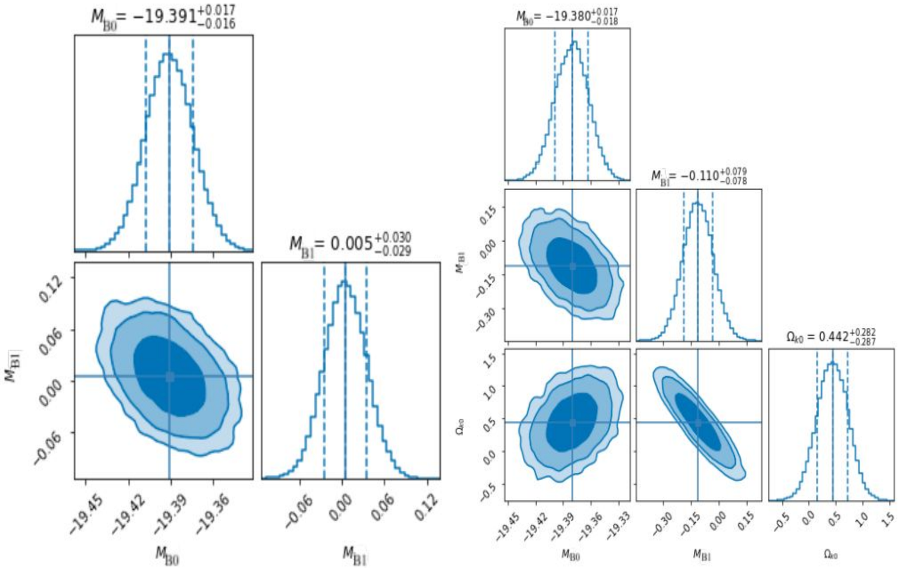


Results: arXiv:2107.04784

- **P4.** $M_B = M_{B0} + M_{B1} \ln z$



Parameter	Flat Universe	Non-Flat Universe
M_{B0}	$-19.391^{+0.017}_{-0.016}$	$-19.380^{+0.017}_{-0.018}$
M_{B1}	$0.005^{+0.030}_{-0.029}$	$-0.110^{+0.079}_{-0.078}$
Ω_{k0}	—	$0.442^{+0.282}_{-0.287}$



Conclusions:

- In the flat and non-flat universe cases, all parametrizations support no evolution of absolute magnitude with redshift with 2σ confidence level.

- For all parametrizations of the absolute magnitude MB, the best fit value of Ωk0 suggests a flat universe at 2σ confidence level.

- However, in the parametrizations P2, P3 and P4, the best fit value of Ωk0 show mild preference for a non-flat universe.

- From the 1D and 2D contours of all four parametrizations of MB(z) for non-flat case, we observed a negative correlation between the absolute magnitude and cosmic curvature which should be analysed further.

THANK YOU!